APPLICATION OF SOIL NAILS TO THE STABILITY OF MINE WASTE SLOPES

by

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Abstract. The traditional soil nailed structure incorporates grouted or driven nails, and a wire mesh reinforced shotcrete facing to increase the stability of a slope or wall. This paper describes the construction and monitoring of a full-scale demonstration of nailing to stabilize coal mine spoil. The purpose of the investigation is to evaluate the performance of nailed slopes in mine spoil using methods proven for the stabilization of soil walls and slopes. The site in eastern Tennessee is a 12 meter high slope of dumped fill, composed of weathered shale chips, sandstone, and coal. The slope was formed by "pre-regulatory" contour surface mining operations and served as a work bench during mining. The material varies in size from silt to boulders, and has a small amount of cohesion. Portions of the mine spoil slope have experienced slope instability and erosion which have hampered subsequent reclamation activities.

Three different nail spacings and three different nail lengths were used in the design. The 12 meter high structure is instrumented to permit measurement of nail strain, and vertical inclinometer readings and survey measurements will be used for the detection of ground movement. The results of this study will aid in the development of design recommendations and construction guidelines for the application of soil nailing to stabilize mine spoil.

Key Words: Soil nailing, slope stability, contour surface mining, spoil piles

Introduction

Throughout the Eastern Coal Province, contour surface (strip) mining has been utilized for the extraction of coal. It is not uncommon for the mine spoil and waste rock removed during mining to form unstable or marginally stable slopes. The materials forming these slopes are generally uncompacted, loose fill comprised of crushed shale and sandstone. This waste rock material forms slopes below contour surface mine high walls, or if constructed after the 1977 Surface Mining Act, may be used to reclaim high wall benches to approximate the original contour. Many of these slopes are active, with ground movement carrying trees and vegetation downslope. Throughout the Appalachian region, buildings and roadways have been constructed on or below the waste slopes. Expensive concrete retaining walls and mechanically reinforced earth structures have been constructed to stabilize the slopes and protect roads and property. In many cases the cost of remediating the slopes is not easily justified. Therefore,

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practical, cost-effective, alternative construction techniques must be developed for the remediation of these slopes.

The application of earth inclusions, or soil nailing, is a proven and effective method for the stabilization of soil walls and slopes (Gässler and Gudehus, 1981; Munfakh et al., 1987; Stocker et al., 1990; Thompson and Miller, 1990; Elias & Juran, 1991). Soil nails are bars or cables, generally steel, used to reinforce a vertical or sloping face, and are usually driven or grouted into place. The construction sequence is depicted in Figure 1 (Clouterre, 1991). The nails are not tensioned and although shotcrete is often applied to

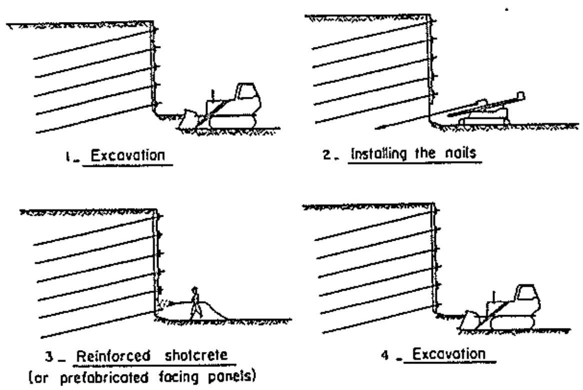


Figure 1 Schematic of soil nailed wall construction process (Clouterre, 1991)

the face, the face treatment plays a minor role in the overall stability. Construction usually occurs from the top down, with the nails gradually being loaded as the excavation progresses and the soil deforms. There are many analytical techniques used, and the construction technique is often governed by site conditions, making the technique somewhat site dependent. However, this is a major advantage of soil nailing, since the design (nail inclination, spacing, and length of nail) can easily be changed during construction based on the observed performance (Mitchell and Villet, 1987).

The purpose of this research program is to evaluate the performance and stability of nailed slopes in mine spoil using methods proven for the stabilization of soil walls and slopes. The application of these techniques to mine spoil materials has not been previously demonstrated or investigated.

Site Description

The site chosen for stabilization is in the Windrock area north of Oak Ridge, Tennessee, and is designated Buffalo Mountain on the Windrock Tennessee topographic map. The surrounding area is a combination of reclaimed sites, partially reclaimed surface mine bond forfeiture sites, and pre-1977 sites. The specific slope identified for the research is a bond forfeiture site that has experienced one or more slope failures since the mining operations were completed. The slope is comprised of loose uncompacted fill material which varies in size. It currently supports little vegetation, thus, construction and subsequent monitoring will be simplified.

The site on Buffalo Mountain is located just above 914 m (3000 ft), and is surrounded by a terrain covered with locust trees and various hardwoods. The appearance of the area changes dramatically from season to season. The site remains wet throughout the year, and from October to April, maintains a semi-frozen state. Figure 2 (Walker, 1995) shows the failure slope and remnants of the original slope, which has come to rest at the bottom of the scarp.

Figure 2 Aerial photograph of Buffalo Mountain site

Numerous contour surface mine operations were conducted in the region. In an investigation of mine spoil stability in the eastern U.S. coal province, Swanson et al. (1983) included two nearby sites that are geologically similar to the Buffalo Mountain site. The sites (in Scott and Anderson counties) are in the Wartburg basin which is "bounded on the southeast by steeply dipping beds which form the boundary between the Cumberland Plateau and the Valley & Ridge Province"(Swanson et al., 1983). The study includes published material properties such as grain size distributions, shear strength, and compaction properties for the mine spoil. A cross section of the mined coal seams and resulting high walls in the Buffalo Mountain area is shown in Figure 3.

was created. A comparison of the two profiles revealed that a spoil pile about 12 m (40 ft) deep was placed in the project area as shown in Figure 6.

Material Properties of Spoil

Two vertical auger borings were drilled from the road crossing the crest of the slope. From the borings, bulk samples of the spoil materials were obtained, and soil nail pullout tests were conducted. Both borings were terminated at a predetermined depth of 9 m (30 ft), which was within the mine spoil. The borings did not encounter residual soil or the mountain face. This was consistent with the profile obtained from the topographic map survey which suggested

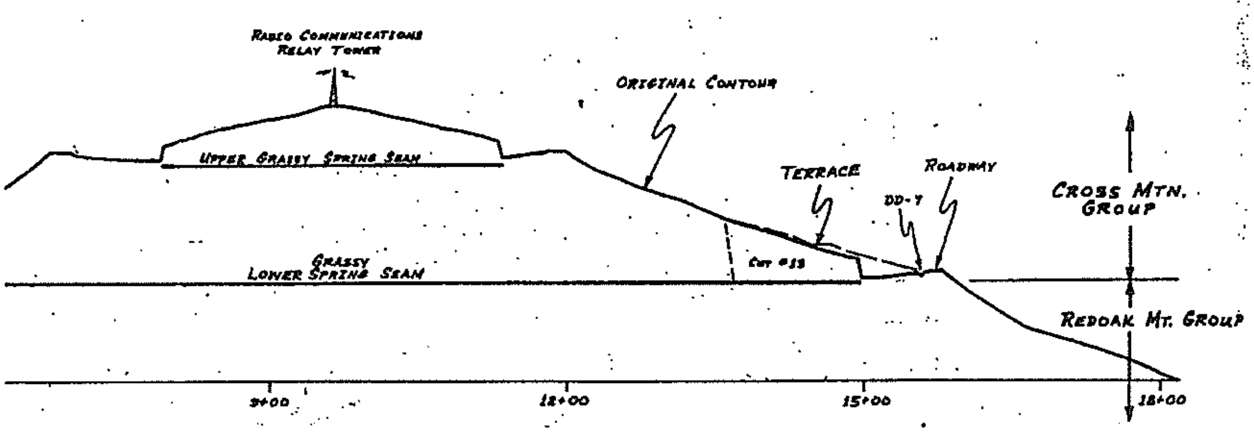


Figure 3 Geologic profile of Buffalo Mountain with strip mine highwalls

Topographic maps from pre-mining and post mining operations

An investigation of the original site terrain was conducted to determine the effects of the mining on the site topography. To investigate these effects, topographic maps from 1952 (before mining) and 1975 (after mining) were obtained. Using the coordinates supplied by the mine operators, the location of the road passing over the slope was found on the 1975 topographic map. Then the same point was located on the 1952 topographic map. Portions of the two topographic maps are shown in Figure 4 and Figure 5. A line (designated A-A) was drawn up and down slope of the road on both topographic maps. From the elevations and distances between contours along this line, a profile of the pre-mining and post mining slope

there was about 12 m (40 ft) of overburden in the slope. No ground water was encountered in either boring.

Two nail pullout tests were conducted to measure the maximum shear stress between the grout and the mine spoil. Test nails were installed in the bore holes, and after the grout cured were loaded to failure. From the pullout tests, an ultimate friction value was obtained which is an important input parameter in the design of the nailing system. The grouted portion of the nails were 200 mm (8 in) diameter and 2.4 m(8 ft) in length. Both tests yielded identical results. Table 1 lists the results of the pullout test.

Cuttings were collected from the

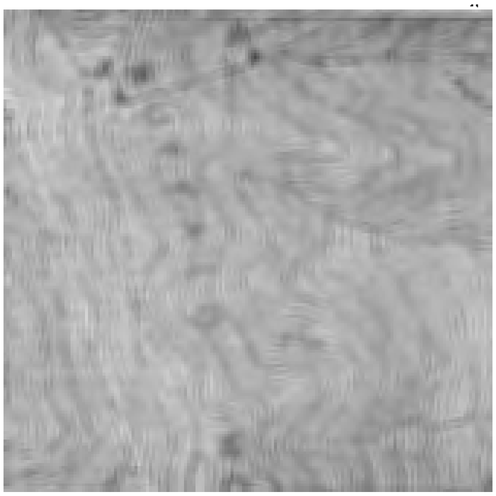


Figure 4 Topographic Map 1952

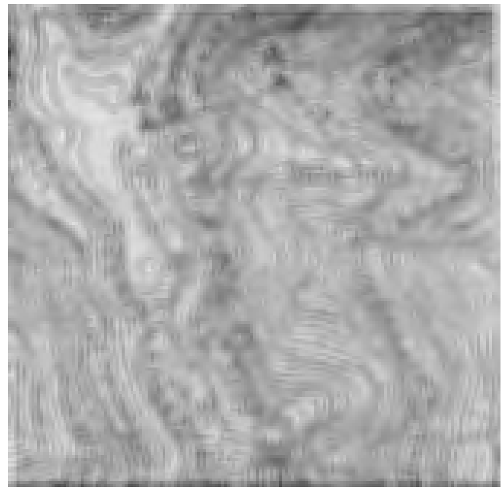


Figure 5 Topographic Map 1975

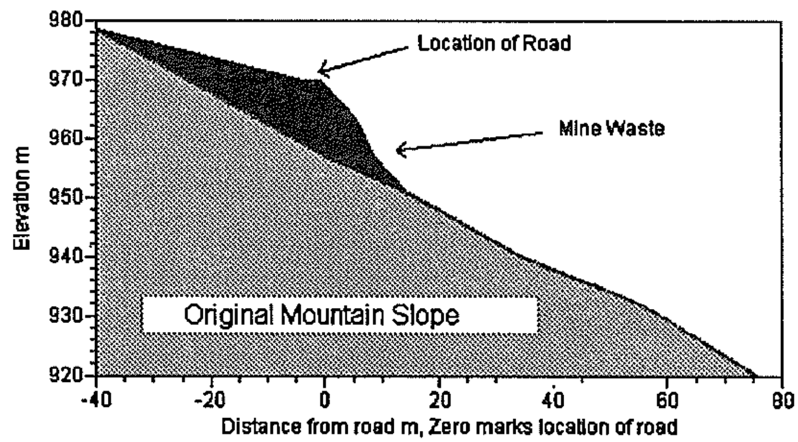


Figure 6 Profile of Buffalo Mountain in 1975 as estimated from topographic maps.

Table 1 Nail Pullout Test Results

Results of Pullout Tests Conducted 3/13/95			
Applied Load at Failure	Surface Area of Soil Nail	Displacement at Failure	Ultimate Stress in Nail
52.6 kN (11.8 kips)	1.56 m^2 (16.8 ft^2)	0.152 mm (0.006 in)	33.7 kN/m^2 (704 lb/ft^2)

boreholes and washed through a #200 sieve. A sieve analysis indicated at least 95% finer than #200. During the #200 wash, it was noticed that some of the spoil material was breaking down which suggests the material is subject to slaking. Atterberg limits were determined on a sample of mine waste from the southwest portion of the slope. The results are shown in Table 2. These results suggest that the mine spoil has a relatively narrow plasticity index, and is therefore unlikely to undergo significant volume change due to water content variation. The material would be classified as a low plasticity silt (ML) by the USCS

Table 2 Atterberg Limits of Windrock Spoil

Sample Origin	LL Liquid Limit	PL Plastic Limit	PI Plasticity Index
Windrock Spoil	31	26	5

classification system (Howard, 1984). The low PI also suggests that the nailed slope will not be subject to significant creep deformation and is well below the maximum value of 20 recommended for permanent soil nailed walls (Elias and Juran, 1991).

In-Place Testing

Due to the granular nature of the material and wide range of particle sizes, undisturbed tube samples for strength testing could not be obtained. Therefore, two in-place borehole shear tests (Lutenegger, 1987) were conducted. The tests were conducted with various consolidation times to determine effective strength parameters. The two tests yielded nearly identical results as shown in Figure 7. A best

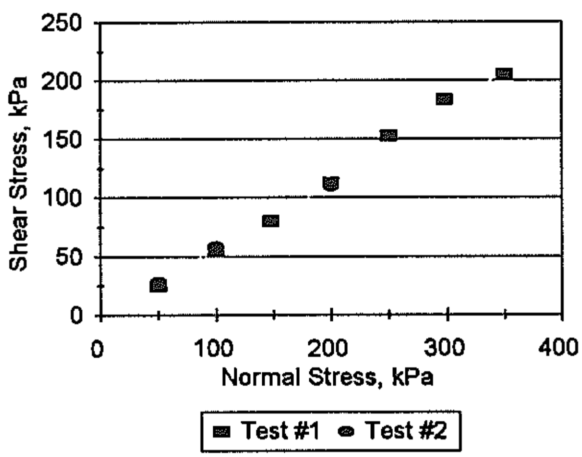


Figure 7 Results of borehole shear tets on Buffalo Mountain mine spoil

fit line through the data yields a failure envelope with a friction angle (ϕ) of about 30°. This was consistent with data reported by Swanson et al., (1983) on remolded samples of mine spoil from nearby mining operations.

Slope Stability Analysis of 1975 Slope Profile

Inspection of the slope suggests that the material possesses a small amount of cohesion that would not be measured in disturbed samples from lab and field tests. To estimate the cohesion, a profile of the slope prior to the failure (Figure 8) was estimated from the 1975 topographic map. This profile was evaluated using the STABL5 (USDOT, 1985; Carpenter, 1986) slope stability analysis program. Using the material properties in Table 3, the STABL5 program was used to back-calculate a value for the cohesion corresponding to a factor of safety, FS=1. The cohesion value was determined to be 8.6 kPa (180 psf).

Stability Analysis and Soil Nail Slope Design

Slope Stability of 1995 Slope Profile

With an estimate of the cohesion it was possible to analyze the existing slope on Buffalo Mountain. A recent slope profile obtained from an optical survey (June 1995) was used in the analysis. The water table was assumed to flow along the original topography of the mountain beneath the spoil and through the toe of the slope. This assumption was based on the absence of water at a depth of 9.0 m (30 ft) in the auger holes in the road and the observation of water at 0.3 m (1 ft) below the slope surface in a hand augered borehole at the toe of the slope. From the STABL5 analysis the factor of safety was found to be about 1.18. A factor of safety greater than one was not surprising since the slope had failed previously, as indicated by the soil mass and trees in Figure 2. Figure 9 depicts the existing slope.

Design and Analysis of Cut Slope

Since the 1995 slope profile was judged to be stable, it was decided to modify the slope to reduce the stability. By creating a steep

Table 3 Properties used in STABL5 analysis of 1975 slope profile.

Dry Unit Weight γ_d	Saturated Unit Weight γ_{sat}	Friction Angle ϕ
16.6 kN/m^3 (106 lb/ft^3)	18.2 kN/m^3 (116 lb/ft^3)	30°

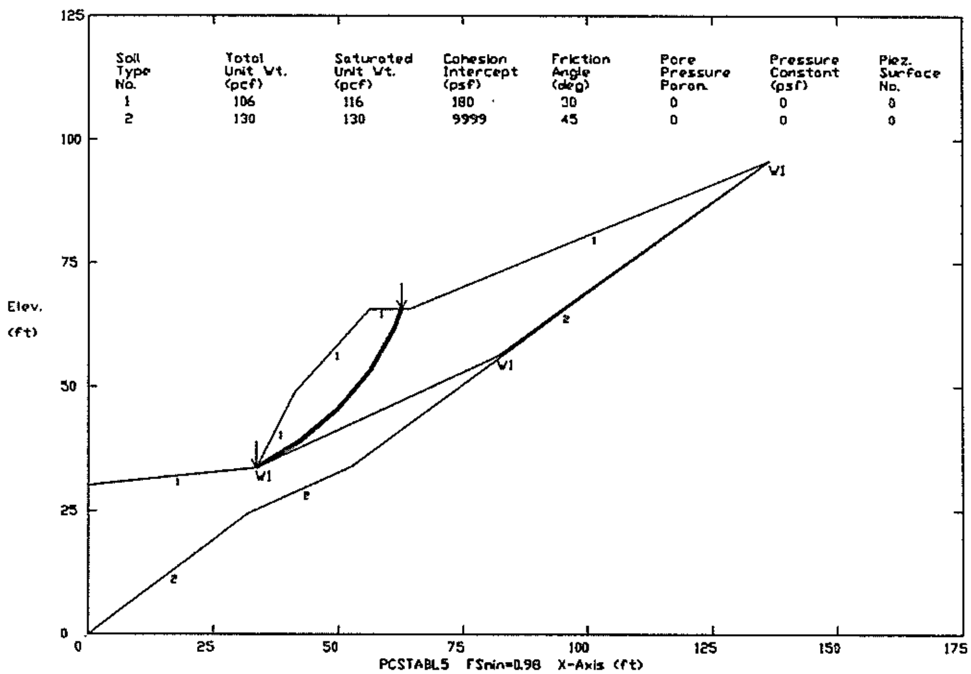


Figure 8 Stability analysis of 1975 slope profile

cut in the toe of the slope the stability was reduced. The highest unreinforced cut in the toe that can be made without instability is around 3.7 m (12 ft). Thus, it was determined that the lower 6.1 m (20 ft) of the slope would be cut as shown in Figure 10. The new slope profile consists of an upper portion 6.1 m (20 ft) high at the natural slope, and a lower portion about 6.1 m (20 ft) high cut to 15° from vertical.

To evaluate different nailing schemes, the new slope was divided into four sections. Three sections have different nailing schemes, and one control section is without nails. The upper natural slope is reinforced with four rows of nails 3.0 m (10 ft) long, spaced 1.5 m (5 ft) vertically, with horizontal spacing consistent with that of the nails below. The various nailing schemes for the lower slope are shown below in Table 4, and an elevation view of the slope is provided in Figure 11. As indicated in Table 4, the nail length as well as the horizontal spacing, S_h and vertical spacing S_v is different in all three sections.

Each section of slope was analyzed using five different methods SNAIL (Caltrans, 1992), EDINA, (Law Environmental Inc., 1991), NAIL (Geoconsult Inc., 1991), the Kinematic method (Elias and Juran, 1991) and STABL5 (USDOT, 1985; Carpenter, 1986). The material properties and resulting factors of safety for each method are listed in Table 5 and Table 6, respectively.

Different factors of safety resulted from different soil nailing analysis methods due to variations in the idealized slope. SNAIL, EDINA, FHWA, and STABL5 were all able to accommodate the natural slope above the cut slope portion in its analysis. For the NAIL program, only

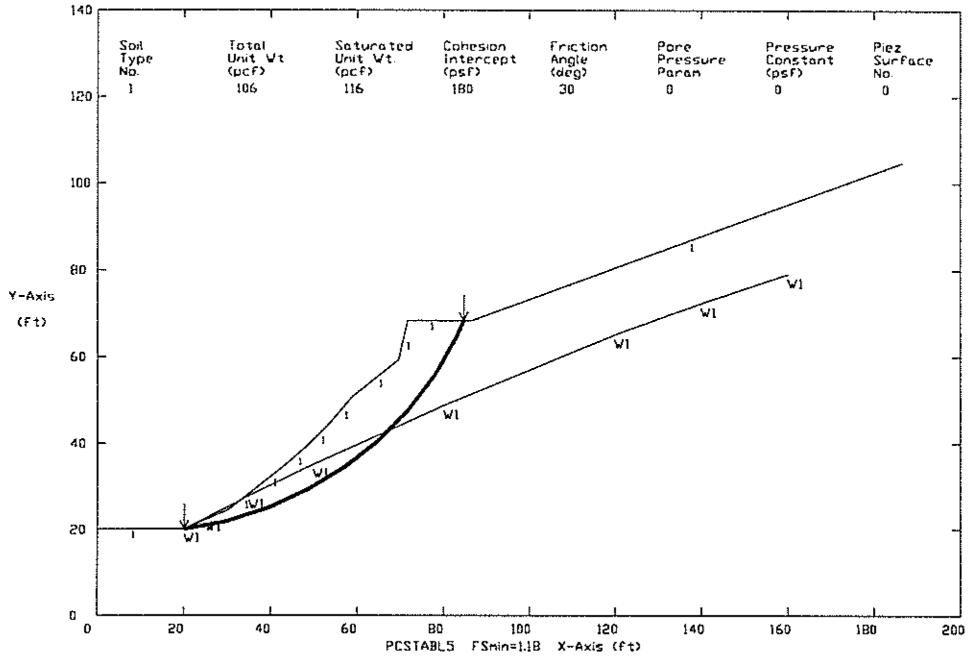


Figure 9 Stability analysis of 1995 slope

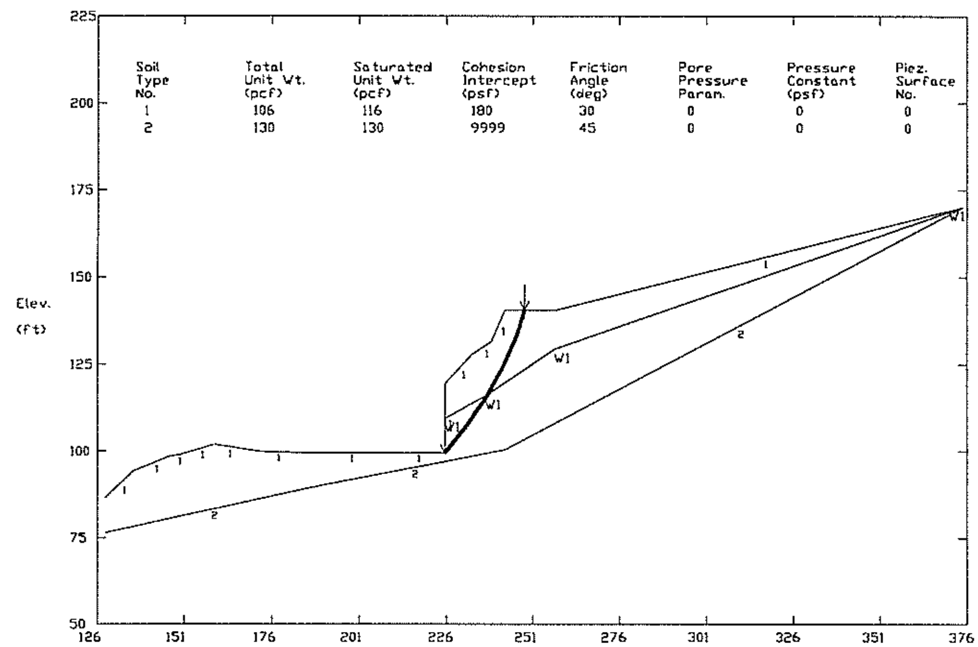


Figure 10 Profile of cut slope used in soil nailing design

Table 4 Summary of Nailing Schemes for Cut Slope

Section Row	Section 1		Section 2		Section 3	
	Sh= 1.5 m (5 ft)	Sv= 1.5 m (5 ft)	Sh= 1.8 m (6 ft)	Sv= 1.5 m (5 ft)	Sh= 1.8 m (6 ft)	Sv= 1.8 m (6 ft)
Row 1 Nail Length	6.1 m (20 ft)		4.6 m (15 ft)		4.6 m (15 ft)	
Row 2 Nail Length	6.1 m (20 ft)		4.6 m (15 ft)		3.0 m (10 ft)	
Row 3 Nail Length	6.1 m (20 ft)		4.6 m (15 ft)		3.0 m (10 ft)	
Row 4 Nail Length	6.1 m (20 ft)		3.0 m (10 ft)		3.0 m (10 ft)	

Table 5 Summary of Material Properties used for Analysis of Nailed Slope

Property	Dry Unit Weight	Saturated Unit	c	Φ
Value	16.6 kN/m^3 (106 lb/ft^3)	18.2 kN/m^3 (116 lb/ft^3)	8.6 kPa (180 lb/ft^2)	30°

Table 6 Summary of Factors of Safety from Stability Analysis

Analysis Method	Program	Section 1	Section 2	Section 3	Section 4 Unreinforced
Stocker and Riedinger (1990)	SNAIL	1.31	1.12	1.06	0.9
Gässler and Gudehus (1981)	EDINA	2.39	1.03	0.83	N/A
Juran et al. (1990)	FHWA Method	1.8 6.1 m (20 ft) Nail	1.25 4.6 m (15 ft) Nail	0.5 3.0 m (10 ft) Nail	N/A
Shen et al. (1981)	NAIL	1.64	1.06	0.91	N/A
Bishop (1955)	STABL5	N/A	N/A	N/A	0.75

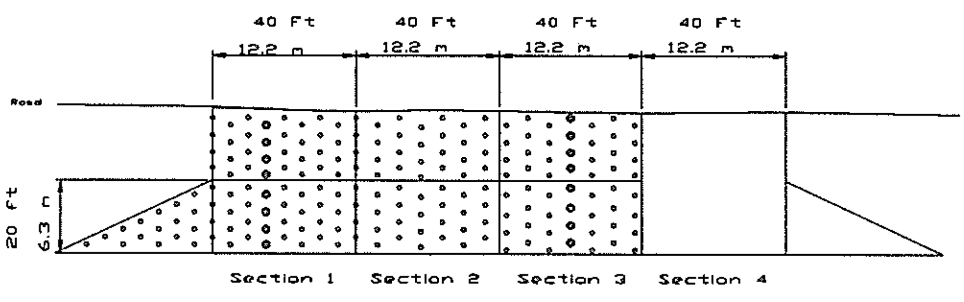


Figure 11 Elevation view of nailing and instrumentation scheme

the cut portion of the slope was analyzed, resulting in slightly elevated factors of safety. In the FHWA analysis only uniform nail length could be analyzed, therefore each section was analyzed using the uniform nail lengths included in Table 6. The results from Table 6 are compared graphically in Figure 12. The results reflect the decrease in the factor of

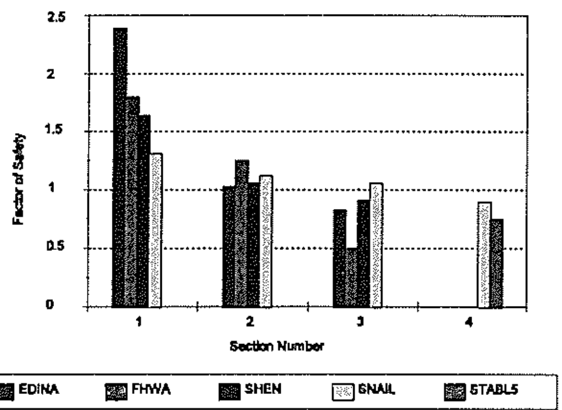


Figure 12 Comparison of factors of safety fo various analysis programs

safety from Section 1 to Section 4. The differences between the results of the analysis methods can be attributed to the difference in the idealized slopes and the manner in which the method is implemented in the computer code.

The purpose of this study is to investigate the effectiveness of soil nailing in mine spoil, therefore the four sections were designed with low factors of safety which would allow deformations of the slope and in the facing that would be observed over the life of the project.

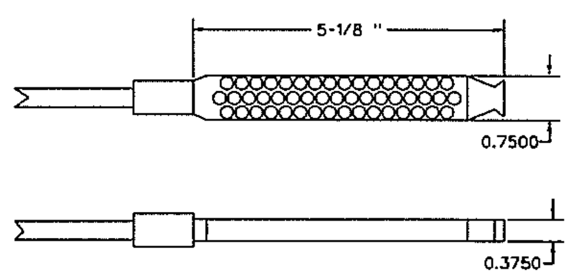
The above analyses were conducted with an assumed water table exiting at the toe of the cut slope. This water table location assumes that the construction will draw the water table down to this elevation. To reflect the worst case water table condition, the analysis was repeated for an elevated, or short-term water table. These conditions reflect the location of the water table as it might be encountered during construction. The results of these analyses are shown in Table 7.

Like many abandoned mine land sites, Buffalo Mountain is very remote and not well suited to the application of shotcrete. Therefore, a reasonable facing which can easily be delivered and installed was selected. The facing of the slope is not the conventional shotcrete and wire mesh facing. Instead, a geosynthetic reinforced erosion blanket was installed, and held in place by steel plates attached to the nails. This should encourage the development and growth of vegetation on the slope to reduce the effects of erosion.

Instrumentation and Monitoring Program

Monitoring of the nailed slope is an important aspect of the research project. The slope deformations are monitored using vertical slope inclinometers, and surveying benchmarks. The slope inclinometers were placed in each of the four test sections and were installed to monitor the slope before, during, and after construction. To assure that the bottom of the inclinometer casing remained stationary, it was installed to a depth of 15 m (50 ft) which is 3 m (10 ft) deeper than the toe of the slope.

To record stresses in the nails, embedment strain gages, model EGP-5-350 manufactured by the Micro Measurements Group (Figure 13) were



Micro Measurements Group EGP-350 Resistance Strain Gage

Figure 13 Embedment strain gage

utilized. In the upper natural slope, two instrumented columns of nails (Section 1 and Section 3) were instrumented as shown in Figure 11.

Table 7 Summary of Factors of Safety from Stability Analysis (Short Term Analysis)

Reference	Program	Section 1	Section 2	Section 3	Section 4 Unreinforced
Stocker and Riedinger (1990)	SNAIL	1.21	1.02	0.87	0.77
Bishop (1955)	STABL5	N/A	N/A	N/A	0.75

Both sections will each have four nails instrumented with gages, with three gages along the length of each nail. The gages are placed at 100 cm (3.2 ft), 180 cm (5.9 ft), and 230 cm (7.6 ft) along the nail relative to the facing end. For the lower portion of the slope, one column in each section will be instrumented as shown in Figure 11. The instrumentation scheme for various nail lengths is listed in Table 8. A minimum of four resistance gages will be used for a single nail.

A permanent benchmark was established to monitor deflections in the face of the slope. Reflectors will be attached along the facing, and a total station system used to monitor movements in the nails and the facing.

Construction And Monitoring

The installation of the nails was underway at the time this paper was prepared. The instruments will be monitored during construction and afterward to obtain measurements of slope deformation, nail deformation, and stress distribution in the nails. The results will be compared with those in the literature for nails in soil. Recommendations will then be made regarding the application of soil nailing to mine waste.

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Table 8 Summary of Strain Gage Placement for Various Nail Lengths

Nail	Gage 1*	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7
6.1 m (20 ft)	45 cm (1.5 ft)	120 cm (4.0 ft)	195 cm (6.4 ft)	270 cm (8.9 ft)	345 cm (11.3 ft)	420 cm (13.8 ft)	495 cm (16.2 ft)
4.6 m (15 ft)	45 cm (1.5 ft)	120 cm (4.0 ft)	195 cm (6.4 ft)	270 cm (8.9 ft	345 cm (11.3 ft)	Not Used	Not Used
3.0 m (10 ft)	45 cm (1.5 ft)	120 cm (4.0 ft)	195 cm (6.4 ft)	270 cm (8.9 ft)	Not Used	Not Used	Not Used

* Location of all gages are relative to the facing end of the nail and is installed at the neutral axis to eliminate effects due to bending.

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